Contract File

PROGRESS REPORT

for

AUGUST, 1965

"RESEARCH AND DEVELOPMENT FOR FABRICATING
A SIMULATED TITANIUM ALLOY CORE SEGMENT
FOR THE S-1C FUEL TANK"

NAS 8-20534

Prepared for

George C. Marshall Space Flight Center

By

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Aero-Space Group
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SUMMARY

During the first nine weeks of Phase I of the contract, significant progress has been made. The full-size gore segment design is complete. A 2 by 3-foot plate of 1/2-inch 8-1-1 titanium has been hot vacuum formed on a die with a saddleback contour. This test verified that the vacuum and elevated temperature was a feasible process for forming the part. A sculptured part (1/2 inch by 2 by 3 feet) has been formed in a sub-scale gore configuration die with considerable success. Diffusion bonding tests appear to be successful, but evaluations are continuing. Preliminary design criteria for the full-size tool is complete and the final design is 50 percent complete. Based upon our schedules to meet the target date of October 8, 19·5, for completion of Phase I of the contract, we are on schedule.

OVERALL PROGRESS

PRELIMINARY DESIGN TASK

The full-size titanium gore design has been completed and presented to Manufacturing and Quality Control for concurrence. The drawing will be reviewed and comments made to Design Engineering before the beginning of the final design task. At the present time, there are no known changes required.

SUB-SCALE TESTING

Sub-scale forming tests and diffusion bonding tests were conducted to obtain processing and tool design criteria for fabricating the full-size titanium gore. These tests are considered to be about 85 percent complete since two of the three major forming tests are complete and the diffusion bonding tests are complete.

The first sub-scale forming test consisted of hot vacuum forming a 2 by 3-foot plate of 1/2-inch 8-1-1 titanium in an existing hot forming die having a saddleback contour. This test was run primarily to verify that the vacuum (29 inches) and elevated temperature (1400 to 1450°F) available in the tool is sufficient to form 1/2-inch thick 8-1-1 titanium plate. The part fit the die completely at elevated temperature, but as the die and part cooled to room temperature, the part was off the die a maximum of 7/32 inch. These preliminary results correlate favorably with our expectations.

The purpose of the second sub-scale forming test was to determine if a 1/2-inch thick sculptured titanium part would form satisfactorily to a simulated full-size gore contour. The 2 by 3-foot part shown in Figures 1 and 2 was formed without wrinkles in the new ceramic form die. However, the test was not 100 percent successful because the part did not conform completely to the forming tool after processing, due to loss of vacuum and incomplete forming of the pockets.

During the heatup cycle, the vacuum was maintained at 26 inches of Hg (1-1/2 hours); however, by the end of the subsequent 1/2-hour soak period, the vacuum dropped to 22 inches of Hg. After 2 hours of cooling to obtain 900°F, the part was observed to be approximately 1/4 inch away from the die at the center of the part. The loss of vacuum was unfortunate; but, the results showed the parts could be formed to this contour without wrinkling.

This test was also intended to show the adequacy of the stainless steel diaphram for pocket forming. It revealed that the pockets would not form to the die without some means of transferring diaphram pressure to the center of the pocket. The pockets were relatively flat from one rib to the next while the ribs were formed to contour.

Final sub-scale test will prove that sufficient vacuum (27 inches of Hg) will form a sculptured titanium part that contains a diffusion bonded reinforcing ring around the fitting hole. Some pocketed area may not form as readily as others, since different shim material will be used in each pocket to determine which is the best for transferring diaphram pressure. The materials to be evaluated for pocket filler are titanium, stainless steel, and alumina sand.

Five diffusion bonding tests were conducted simulating the requirement for the full-size gore. The tests were run on a tool fabricated for this program. (See Figures 3, 4, and 5.) An 8-1-1 titanium ring, 1/2-inch thick with a 5-1/2-inch inside diameter and an outside diameter of 9 inches was diffusion bonded to an 8-1-1 titanium base plate, 20 inches square and 1/2-inch thick. This base plate has a 5-1/2-inch diameter hole to accommodate the ring. The first and second tests were not successful because of temperature sensing problems that caused excessive heating and consequently melting and fusion of tool and part elements. The temperature sensing problem was corrected, and the third and fourth tests were successful. Micro examination of bond area and grain structures established the process as a maximum of 1850°F with 200 psi contact pressure for one hour. Pressures up to 1500 psi were used to limit contamination of faying surfaces during the 12 to 15-minute heatup period before the joint reached 1500°F, but pressures must be reduced to 500 psi or less to preclude excessive reduction in thickness of the part as higher temperatures. The fifth test consisted of diffusion bonding the ring to a sub-scale part, 1/2-inch by 2-feet by 3-feet, for the hot vacuum forming tests. The bonding operation appears to be successful, but further evaluation will be made after the forming test to verify this.

It is intended that forming of the sculptured, diffusion bonded part be the last sub-scale test since the process parameters are largely determined and all that remains is the demonstrated proof from a sample part. The process development and tool design sections reflect what has been learned from the sub-scale testing that applies to each of these functions.

PROCESS DEVELOPMENT

Detail operations of the fabrication process to be used in making the full-sized gore were determined from the sub-scale testing.

The process set forth in the proposal and pictured in the sequence chart attached included the following:

1. Purchase material to the current Boeing mill anneal specification.
2. Diffusion bond (of reinforcing ring) by applying 5000 to 10,000 psi during heatup and reducing the pressure to about 30 psi at bonding temperature of 1700 to 1800°F, allowing a 1-hour soak time at temperature for bonding.
3. Hot flatten the bonded assembly in a furnace by soaking between mild steel plates for 2 hours at 1200°F.
4. Machine pocket areas prior to forming.
5. "Hot" form the gore in a ceramic die by heating the part to 1450°F in 30 minutes and holding it at temperature for 30 minutes and then cool at a uniform rate not to exceed 100°F per hour from 1450 to 900°F. Use vacuum to form the part against the die during this cycle.
6. Finish trim part to remove forming excess.
7. Clean part as required to prevent excessive oxidation and to obtain an acceptable surface condition.

At the present state of development, the process is basically the same except the diffusion bonding and the forming cycles have been modified.

Diffusion bonding of the ring would be accomplished by applying pressures up to 1500 psi during the 15-minute heatup period. This pressure is reduced to 500 psi at the bonding temperature of 1850°F. The soak time will be one hour at 1850°F using 200 psi pressure.

The forming cycle now consists of a 90-minute heatup to 1450°F and 30-minute soak at this temperature with the previously specified cooling rate of no more than 100°F per hour from 1450 to 900°F. During this cycle 27 inches of Hg vacuum will be maintained to provide the necessary forming pressure. The heatup cycle was changed from 30 to 90 minutes because of the excessive power requirement in the full-size die, associated with the short cycle. Recent calculations indicate the 30-minute cycle would require approximately 500 KVA power; however, the contract is limited to equipment capable of 300 KVA power; therefore, the longer cycle was selected since it will not jeopardize the quality of the finished part.

FULL-SIZE TOOL DESIGN

The preliminary tool design criteria has been established, and the final tool design is 50 percent complete.

The size of the hot vacuum form tool has been increased since last reported, from 10 by 15 feet to 14 by 19 feet. The following explanation is given for the increase in size.

1. When the vacuum system is used with the tool, it in effect becomes a pressure vessel. Therefore, the tool must be designed to meet pressure vessel codes. The pressure of the atmosphere on the bottom of the tool has been estimated to be over 250 tons.

2. There is approximately 6 inches of excess material on all sides of the part. This gives a blank size of approximately 8 by 13 feet.

3. Based on previous tests, we will require 6 inches of heated zone in the tool beyond the blank size. Therefore, the tool size is increased to 9 by 14 feet.

4. Three feet more on all sides is needed for insulation between the heated zone and the steel framework, for fairing the ceramic portion to the steel framework for a lead-in of the diaphram, and to allow the contour of the die to swept-in. This increases the size of the tool to 14 by 19 feet. The tool contour must be obtained by sweeping rather than the more conventional method of

fabricating to a plaster model. The sweeping will involve moving a single template through an arc to produce the finished die surface. The size of the tool precludes the use of conventional methods.

The current tool design criteria for design is as follows:

1. The die will be 14 feet wide, 19 feet long, 4-1/2 feet high and weigh about 45,000 pounds. The construction will consist of a steel box mounted on "I" beams and filled with ceramic.

2. The inconel tubing used for the heating elements will be imbedded 3/8 inch under the surface of ceramic. The tubing will run the long way of the die except at the ends were a few tubes will run the opposite way for better heating control.

3. The spacing of the tubing will be approximately 0.60 inch.

4. The size of the inconel tubing is 1/4-inch diameter with 0.018-inch wall thickness for the main part of the die. A small number of tubes for edge heating will be 3/16 inch in diameter.

5. The power requirements for heating of the die will be 300 KVA using a 1-1/2-hour heatup time and 1/2-hour soak time.

6. The part will have approximately 6 inches of excess material on all sides.

7. The vacuum system to draw the part blank to the contour of the tool will be capable of pulling 27 to 29 inches of Hg.

8. Air will be forced through the inconel tube heating system to provide uniform cool down of the part after forming. The cool-down system will be used only when electrical power is off.

9. The maximum temperature on the outside of the steel box of the tool will be approximately 200°F.

10. The die is being designed to be capable of heating a part to 1450^{+75}_{-25} °F.

11. The diaphram will be 0.020 to 0.030-inch gage stainless steel.

MISCELLANEOUS CONSIDERATIONS

NASA previously authorized Boeing to buy inconel tube heating elements for the full-size forming tool as of August 1, 1965, and the titanium material for the full-size gore segment as of September 1, 1965. However, further approval of the titanium purchase has been subsequently required by NASA.

The inconel tube heating elements have been ordered for the full-scale tool to be fabricated in Phase II. The titanium for the full-size gores to be fabricated in Phase III will be ordered in the next few days and will be accomplished as required by Clause 9 of the General Provisions of the contract.

The size of the tool has increased considerably from that planned in the proposal. Consequently, we expect the forming tool costs to be approximately double the original estimate of $30,000.

Problems

Work to date has not revealed any major problems other than the tool costs described above.

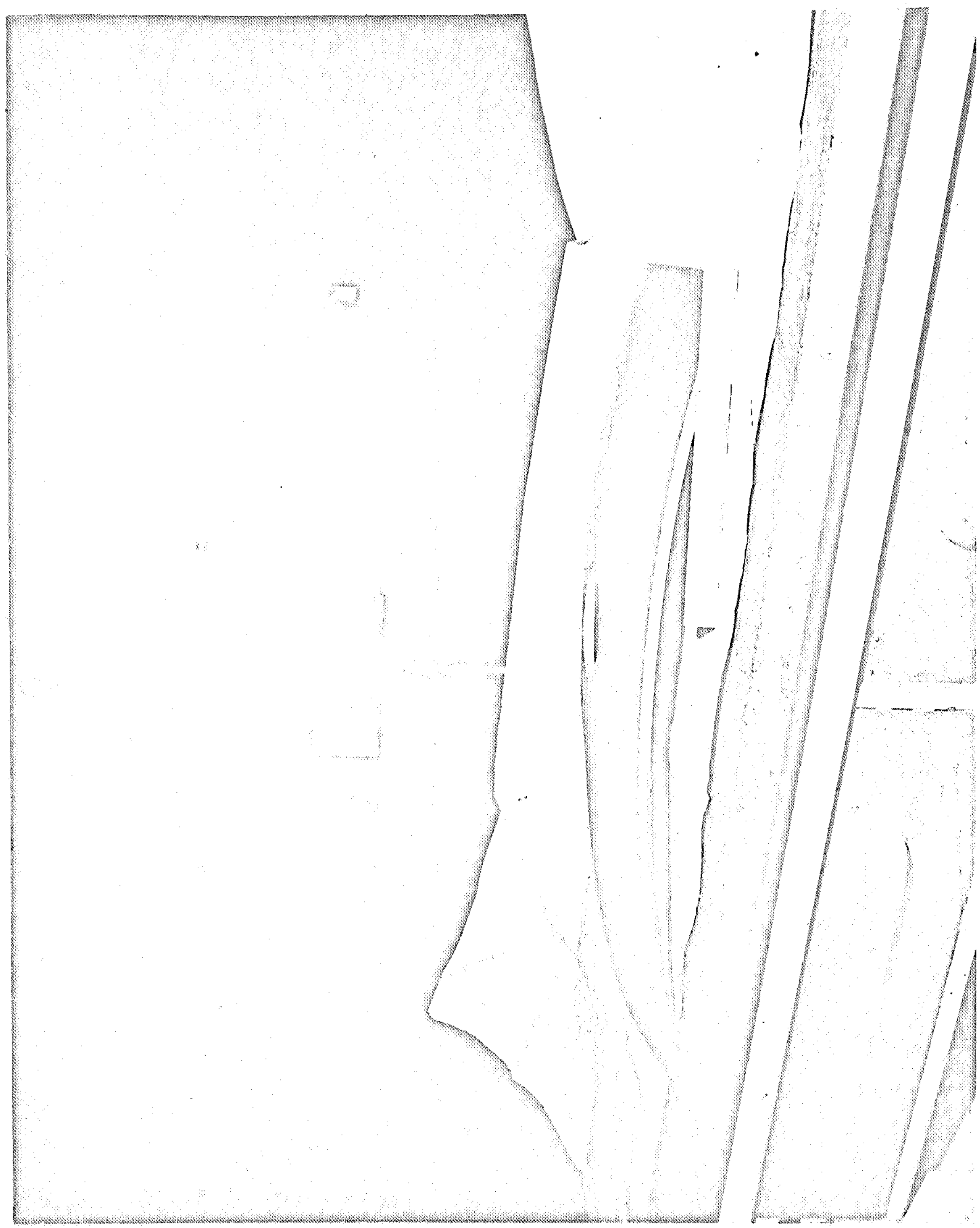


FIGURE 1: OUTSIDE SURFACE OF A SUB-SCALE 1/2-INCH THICK TITANIUM GORE THAT HAS BEEN HOT VACUUM FORMED

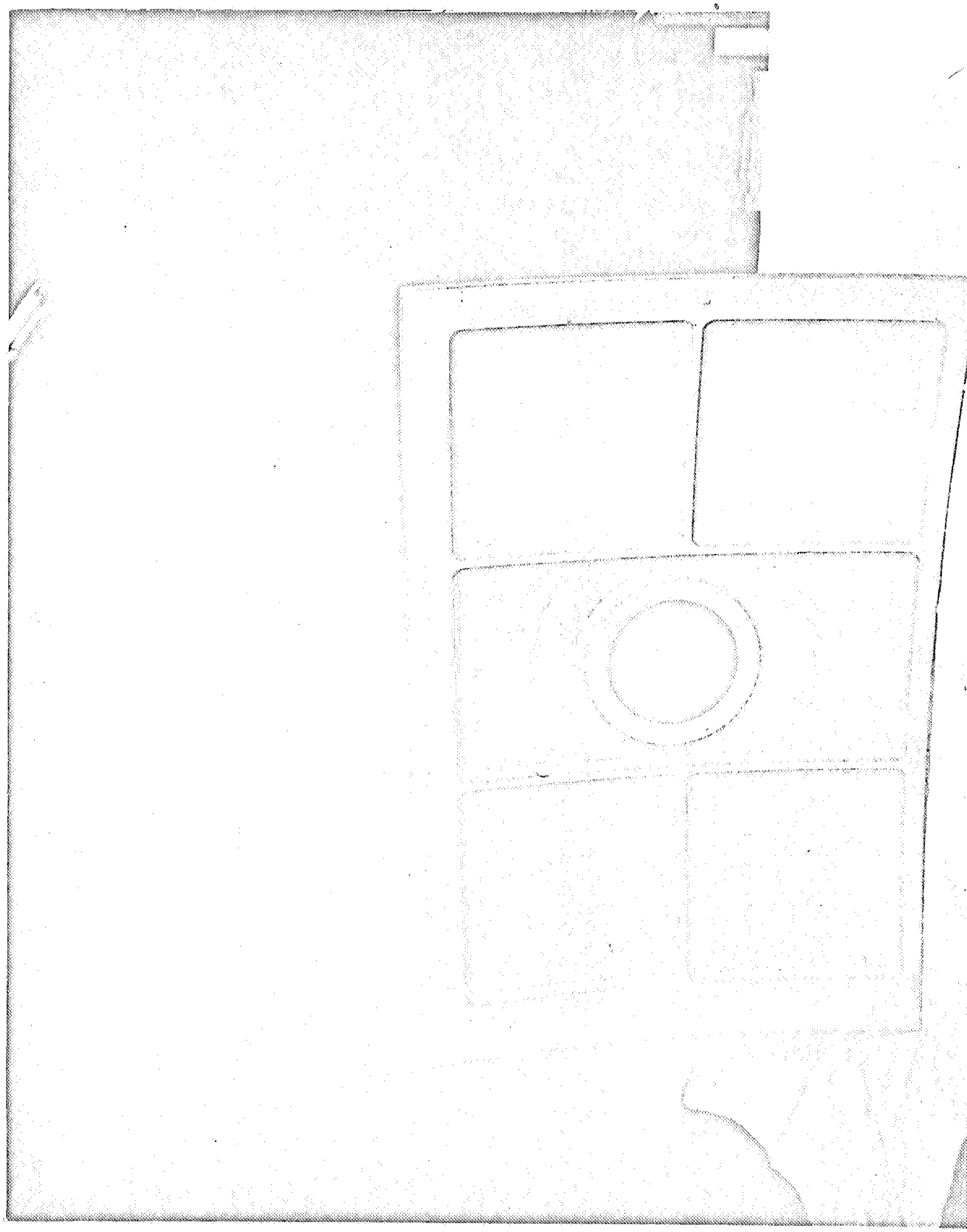


FIGURE 2: SCULPTURED SIDE OF A 1/2-INCH THICK GORE THAT HAS BEEN HOT VACUUM FORMED

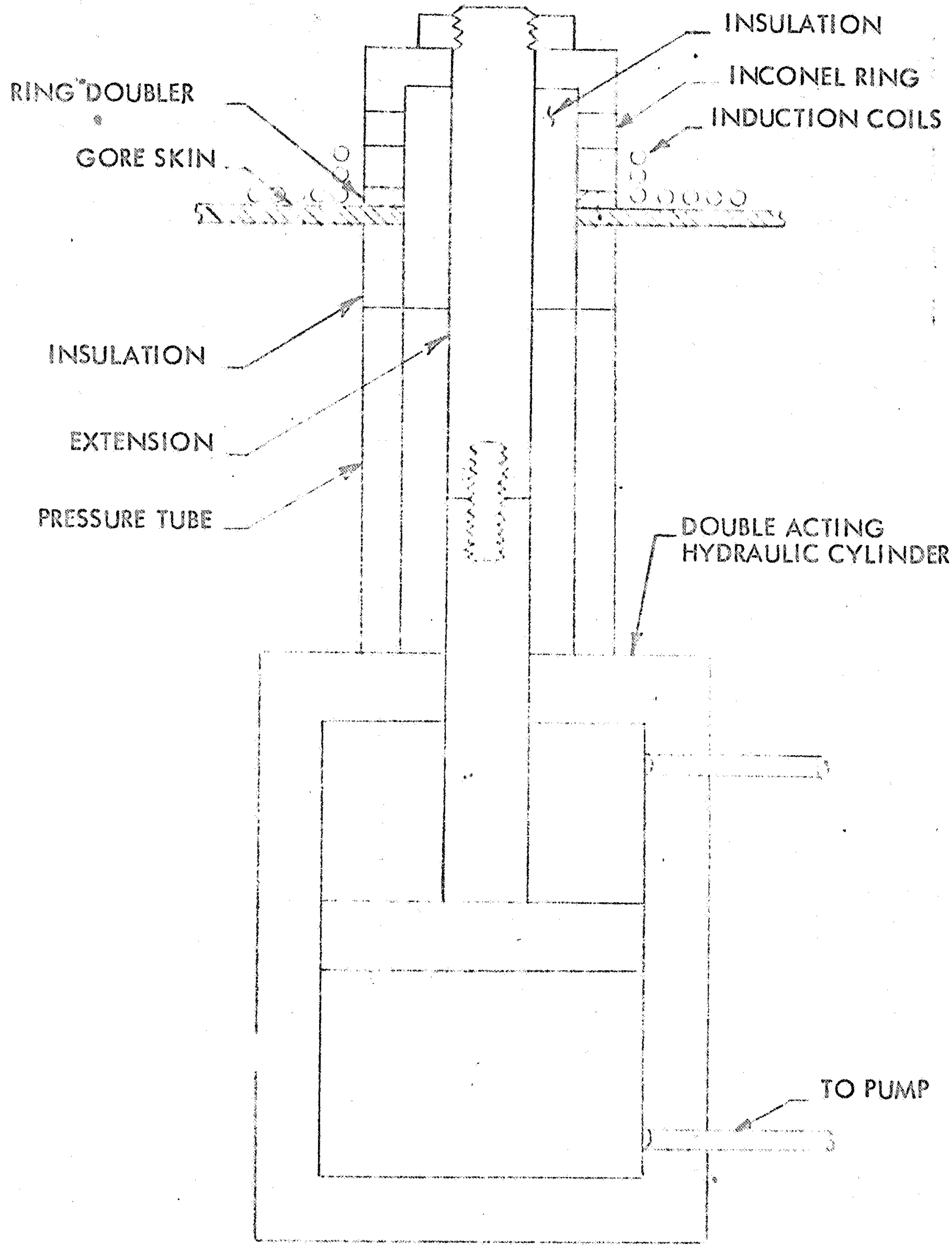


FIGURE 3: DIFFUSION BONDING - SCHEMATIC TOOLING DIAGRAM

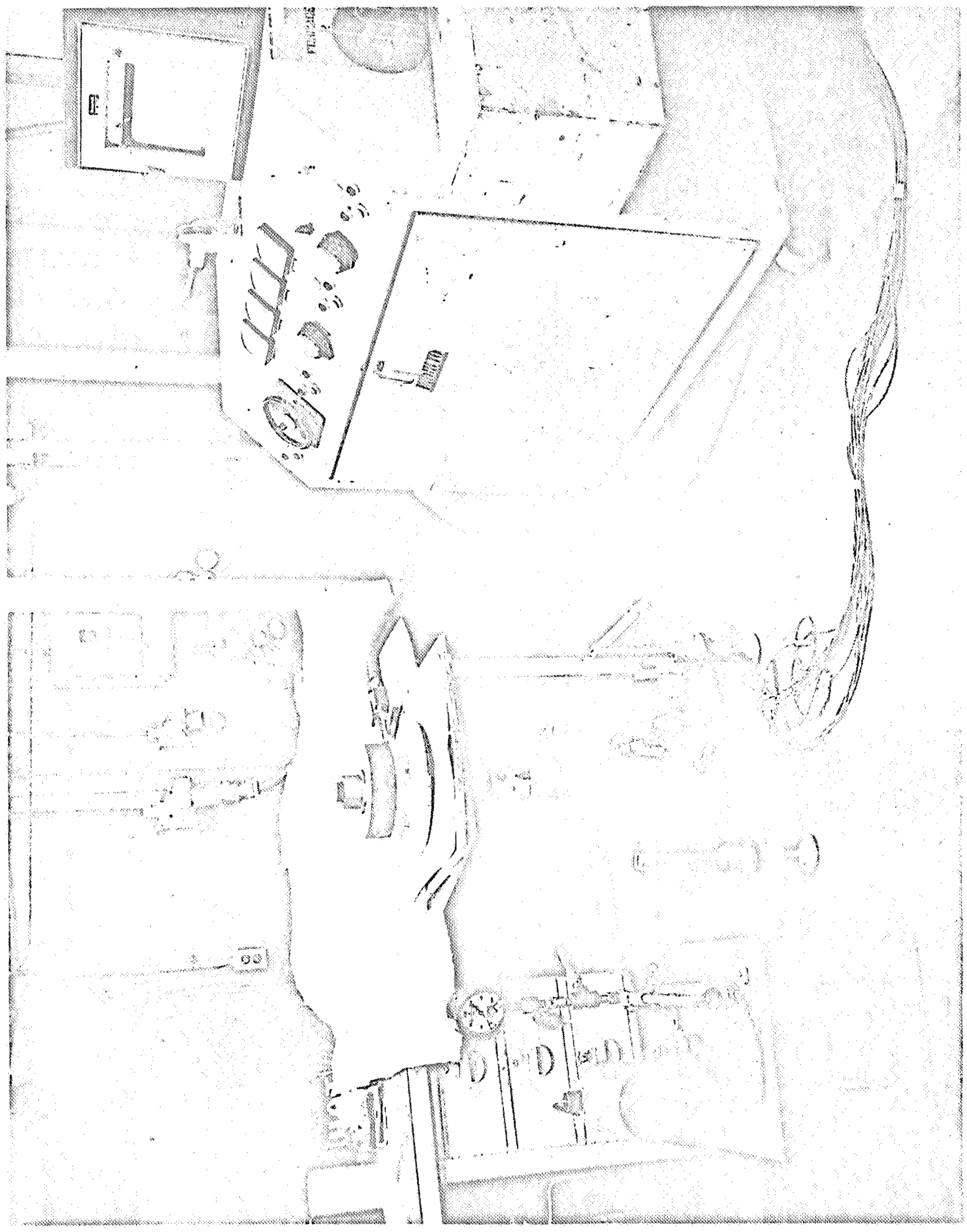


FIGURE 4: OVERALL VIEW OF THE DIFFUSION BONDING TOOL BEING USED TO BON A 1/2-INCH THICK TITANIUM RING DOUBLER TO A 1/2-INC THICK TITANIUM PLATE

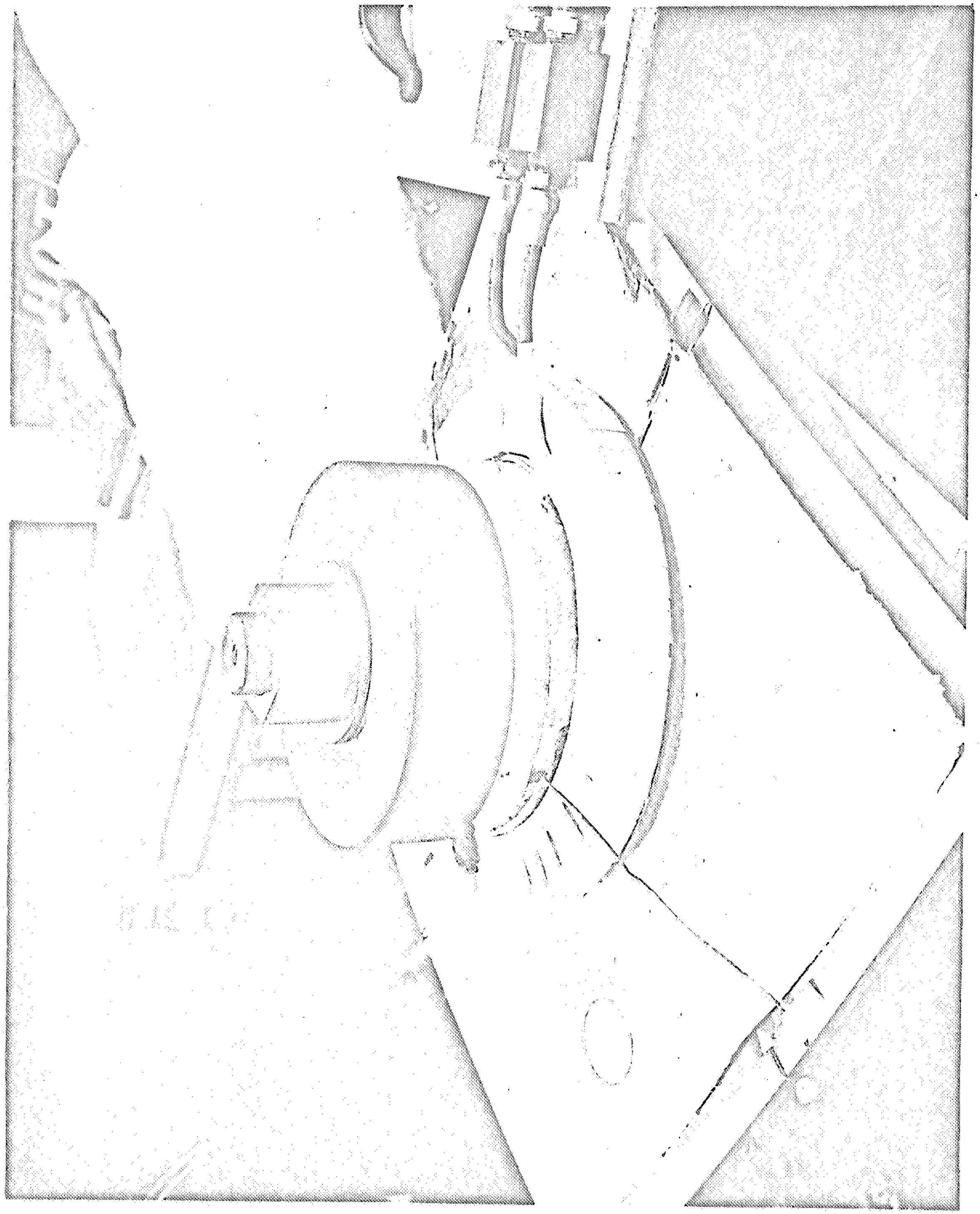
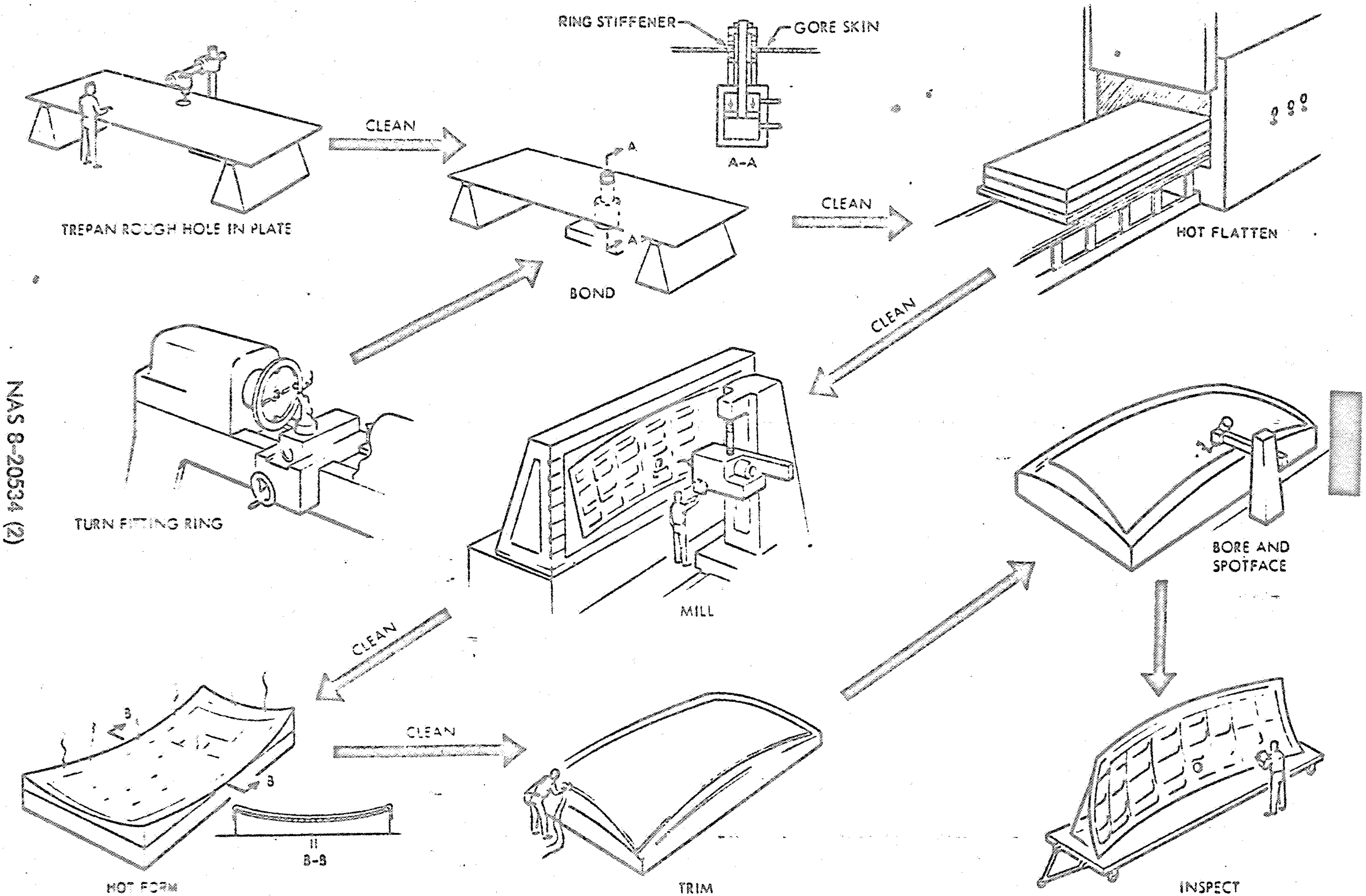


FIGURE 5: VIEW OF THE PRESSURE RING AND INDUCTION COIL OF THE BONDING TOOL BEING USED TO BOND A 1/2-INCH THICK TITANIUM RING DOUBLER TO A 1/2-INCH THICK TITANIUM PLATE



FABRICATION SEQUENCE CHART

RESEARCH & DEVELOPMENT FOR FABRICATING A SIMULATED TITANIUM ALLOY BASE GORE SEGMENT, LOWER BULKHEAD, FOR THE S-1C FUEL TANK

NAS8-20534

PERIOD THROUGH AUG 1965